stelpipe

X80 (Grade 550) PIPEMAKING

for

Department of Energy, Mines & Resources
CANMET-MTL Division

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STUDY OF LARGE DIAMETER PIPE DEVELOPMENT <PART OF THE PROGRAM OF THE FEDERAL PANEL ON ENERGY R&D (PERD) COST SHARED

FINAL REPORT BY:

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EXECUTIVE OVERVIEW

Stelpipe wants to determine its capability of producing X80 large diameter line pipe and qualify a suitable skelp supplier. The increase in worldwide demand for energy in recent years has encouraged exploration and further development of new and existing oil and gas fields. With this has occurred a push for higher grade steels such as API 5L X80 (CSA Grade 550) which can operate at higher transmission pressures. Stelpipe is interested in bidding on future X80 lines, but does not know if its pipe mills can successfully manufacture this grade of line pipe. Since there are no North American suppliers of suitable skelp, Stelpipe needs to locate and qualify a supplier.

This report details the skelp properties achieved by two European Steel Mills: Dillinger, West Germany and GTS, France, and the resulting 1219mm OD x 11.7mm WT spiral pipe properties obtained from these skelps. The following conclusions were drawn from the results:

1. Stelpipe's Stelform Mill is capable of successfully manufacturing 1219mm x 11.7mm WT, API 5L X80 line pipe.

2. Overall, the French steel (GTS) exhibited the best combination of pipe mechanical properties. Pipe produced from both steel sources displayed mechanical properties similar to those published in the scientific literature.

3. Plate characteristics were remarkably uniform both along the plate length and across the plate width. The German steel (Dillinger) displayed the best mechanical properties in plate form.

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SOMMAIRE

La firme Stelpipe veut évaluer sa capacité de fabriquer des conduites X80 à grand diamètre et trouver un entrepreneur capable de lui fournir les bandes d'acier à tuyaux dont elle a besoin. L'augmentation de la demande mondiale d'énergie au cours des dernières années a encouragé la prospection et fait s'intensifier l'exploitation des champs de pétrole et de gaz nouveaux et existants. Concurremment, on a réclamé de l'acier de qualité supérieure, tel que du API 5L X80 (nuance 550 de CSA), pouvant tolérer de plus hautes pressions de service. Stelpipe est intéressée à soumissionner des travaux de fabrication de conduites X80, mais elle ignore si ses laminoirs à tubes peuvent fabriquer ce type de tuyaux. Comme il n'y a pas en Amérique du Nord d'entreprises pouvant lui fournir les bandes à tuyaux dont elle a besoin, Stelpipe doit trouver un fournisseur qualifié.

Le rapport détaille les propriétés des bandes à tuyaux fabriquées par deux aciéries européennes, la société allemande Dillinger et la société française GTS. Il décrit également les propriétés des tuyaux spiralés de 1 219 mm de diamètre externe et 11,7 mm d'épaisseur de paroi fabriqués à partir de ces bandes. Des résultats de l'étude, il découle ce qui suit :

1. Le laminoir Stelform de la firme Stelpipe peut fabriquer des conduites API 5L X80 de 1 219 mm de diamètre extérieur et 11,7 mm d'épaisseur de paroi.

2. En général, l'acier français (GTS) présente la meilleure combinaison de propriétés mécaniques pour des tuyaux. Les tuyaux fabriqués avec l'acier de l'une ou l'autre des deux firmes présentent des propriétés comparables aux valeurs publiées dans la littérature scientifique.

3. Les caractéristiques des plaques sont remarquablement uniformes autant longitudinalement que transversalement. L'acier allemand (Dillinger) montre de meilleures propriétés mécaniques sous forme de plaques.

INTRODUCTION

The increased worldwide demand for energy in recent years has encouraged exploration and further development of new and existing oil and gas fields. In Canada, large reserves of natural gas are known to exist in the northern Arctic regions.

Plans to tap these resources were made in the late seventies but did not materialize, largely because of political and economic considerations. Now with rapidly rising energy costs, there is renewed interest in opening up these Arctic gas fields and in the construction of a pipeline system to transport the gas to southern markets in Canada and the US. Projected tonnage for the Arctic pipeline is close to one million tons. The design will probably be for X80 pipe and a wall thickness for the main line of approximately 12.5 mm (0.5in.); X80 pipe is ideal because of its ability to handle higher transmission pressures. In order to bid on this project and others like it, Stelpipe needed to determine its ability to manufacture X80 pipe. In the winter of 1990, Stelpipe requested Steltech to design an X80 pipemaking trial on the Welland Tube Works Stelform Mill. As Stelco Steel did not produce X80 skelp, a purchasing specification for skelp suitable to produce X80 pipe was created then negotiated with Franco Steel (Appendix I). Stelpipe subsequently purchased 135 tons and received plate from two Franco Steel held companies: Dillinger (West Germany) and GTS (France). The trial was conducted during the final week of August 1990. This report presents the results of that trial.

Procedure

The spiral forming line was set up to produce 1219 mm OD x 11.7 mm WT pipe from the 24 plates utilized in the trial (Table I). Standard welding consumables and parameters for this pipe size were employed. The welded pipe was mechanically expanded 1.5%. After expansion, the pipe was hydrotested at a nominal pressure of 1540 psi for 10 seconds. All pipe welds underwent full visual, x-ray, and ultrasonic inspection; all cross welds were subjected to dye penetrant checks.

TABLE I: Plate Identification

SUPPLIER	HEAT NO.	SUPPLIER PLATE No.	SUPPLIER	HEAT NO.	SUPPLIER PLATE No.
Dillinger	96179	63914	GTS	22687	3432
		63915			3434 *
		63916			3435
		63917			3436
		63918			3437
		63919			3738
		63920			3439
		96566			3440
					3441

* - plate set aside for mechanical testing

Results

Overall, plate quality was good. Several plates from both sources contained some minor surface tears but these were later ground out. However, five German plates were received in a badly waved condition and so could not be used on the mill. One of these plates also displayed some severe edge gouges. These defects have been attributed to poor handling during unloading at the receiving dock.

No major difficulties with the forming and welding operations were experienced during the trial. The incidence of weld defects was low; the weld imperfections observed were: starved welds, burn through, and minor porosity. One pipe (no. 9) contained a transverse crack on the north cross weld. Forming defects were also few in number. Some surface tears resulted from forming; however, these were subsequently ground out.

No problems were observed during mechanical expansion; however, several pipe (nos. 4, 5, and 7) made from the German plate experienced growth during hydro-testing. These pipe were subsequently downgraded to seconds because of a too-large outside diameter.

Only pipe no. 7 exceeded the maximum OD value (based on API 5L [1]); otherwise, this pipe and all others met the API tolerances for OD and WT. All pipe met the maximum OD criterion for out of round but failed to meet the minimum requirement (Table II).

TABLE II: Dimensional Values for the X80 Pipe

PIPE #	OUTSIDE DIAMETER (mm)		W. T.(mm)		OUT OF ROUNDNESS (mm)	
	Min.	Max.	Min.	Max.	Min.	Max.
1	1218.95	1220.47	11.71	11.91	1193.80	1196.38
2	1218.44	1222.50	11.35	11.73	1190.62	1196.38
3	1219.45	1220.47	11.29	11.56	1192.21	1196.38
4	1219.20	1225.04	11.43	12.01	1190.62	1198.56
5	1219.96	1224.28	11.56	11.96	1190.62	1198.56
6	1219.20	1220.72	11.63	12.01	1190.62	1196.98
7	1219.45	1225.80	11.86	11.99	1190.62	1200.15
8	1218.18	1221.23	11.58	12.06	1190.62	1196.98
9	1218.18	1220.72	11.51	11.78	1190.62	1196.98
10	1219.18	1220.72	11.58	11.76	1193.80	1195.39
11	1218.44	1220.47	11.76	11.89	1190.62	1195.39
API 5L SPEC *	1216.0	1225.55	10.77	13.99	1207.01	1231.39

* - The minimum and maximum values have been determined using the nominal outside diameter and wall thickness and the tolerances specified in API 5L.

Discussion

Overall, pipemaking occurred with little problems, thus confirming Stelpipe's ability to successfully manufacture X80 1219 mm OD x 11.7 mm WT linepipe. Further trials would be needed to verify Stelpipe's ability to produce other sizes; however, it is unlikely that X80 pipelines would require pipe in wall sizes greater than 12.7 mm (0.5in.).

The occurrence of growth during hydrotesting of pipe made from the German skelp can be attributed to the discontinuous yielding behaviour of the German plate; the French plate exhibited continuous yielding and hence, no pipe growth. The cumulative tensile hoop strain incurred from forming, mechanical expansion, and then hydro-testing was likely sufficient to place the material in the discontinuous yield portion of the stress-strain curve. Consequently, the pipe would grow with a corresponding decrease in gas pressure because of the increase in internal volume (due to the greater ID). This is in fact what Stelpipe Operating personnel reported during hydro-testing. The discontinuous yielding behaviour of the German steel is symptomatic of its ferrite-pearlite micro-structure. The French steel had a significant Mo addition (0.21 wt.%; Table III),

TABLE III: Heat Chemical Compositions of X80 Steels

		Chemical Composition (wt%)														
Plate Supplier	Heat #	C	Si	Mn	P	S	Al	Cu	Mo	Ni	Cr	V	Nb	Ti	B	C.E.
Dillinger	86179	0.08	0.43	1.67	0.011	0.001	0.035	0.008	0.008	0.026	0.028	0.08	0.040	0.002	0.0001	0.27
GTS	22687	0.07	0.38	1.64	0.010	0.001	0.025	0.01	0.21	0.02	0.02	0.07	0.05	-	0.0003	0.27

which eliminates the yield point elongation phenomenon (with the creation of a ferrite-bainite microstructure); the German steel had a Mo level of only 0.008 wt.%. Therefore, to avoid this problem in the future, the Dillinger steel chemistry and/or processing (such as use of accelerated cooling) would have to be modified.

PIPE MECHANICAL PROPERTIES

Procedure

Of the eleven pipes which were produced, five were sampled for mechanical testing: pipe nos. 1 and 6 (Dillinger plate) and pipe nos. 8, 9, and 10 (GTS plate).

For tensile testing, six specimens were prepared from each pipe: two body samples from each of two plates/charges (longitudinal and transverse directions) within that pipe and one transverse sample each from the spiral weld and cross weld. Tests were performed according to ASTM E8 [2].

In addition to pipe tensile testing, all-weld-metal tensile tests were performed on pipe nos. 2 (Dillinger plate) and 11 (GTS plate). Three mini tensile specimens were prepared from the spiral weld and cross weld of each pipe. Each specimen had a nominal diameter of 3.81 mm and was tested according to ASTM E8 and ASTM A370 [2,3].

Full-size Charpy V-notch specimens were tested according to ASTM E23 [4]. Three transverse specimens were prepared from the body of two plates/charges from each pipe and tested at temperatures of: -5, -25, -45, -60, -65, and -70 degrees C.

Battelle Drop Weight Tear Tests (BDWTT) were performed on three transverse body samples from each of two plates/charges within a pipe. The specimens were tested at temperatures of: -5, -15, -25, -35, -45, and -60 degrees C.

Hardness traverses were made on polished transverse sections of cross seam and spiral welds from pipe nos. 2 and 11. Three traverses were made on each weld section: one at the mid-plane, one 1.5 mm from the OD and one 1.5 mm from the ID. The impressions were made with a 500 g load.

The heat affested zone (HAZ) metallurgical stuctures of both the cross and spiral welds were investigated as well using the hardness coupons from pipes 2 and 11.

Stelpipe submitted samples of both steels to Graville Associates' Joint Industry Project "Evaluation of Steels for Sensitivity to Hydrogen-Induced Cracking in the Reheated HAZ". Stelco's plate for X70 (Grade 483) pipe had been previously tested. Two specimens from each steel were slow bend tested at the Welding Institute of Canaa to assess their field weldability.

Both guided bend tests (pin diameter 110 mm) and side bend tests (pin diameter 38.1 mm) were performed on cross weld and spiral weld specimens from pipe nos. 1, 6, 8, 9, and 10. For the side bend tests, 4 specimens per weld location per pipe were tested; whereas, for the guided bend tests, 2 specimens per weld location per pipe were tested.

Cross welds and spiral welds from each pipe were analyzed for chemical composition and tested for Charpy V-notch impact toughness at 6 temperatures, 3 specimens per temperature, using full size transverse samples, machined from the mid-wall position and notched on the weld centerline in the through thickness direction.

Other than the all-weld-metal tensile tests and the hardness traverses, all testing and specimen preparation were performed at Welland Tube Works. The all-weld-metal tensile tests and hardness traverses were carried out at Steltech. The weld chemical analyses were done at Page Hersey Works Chemical Laboratory.

Results

* Steel Chemical Composition

Both the Dillinger and GTS steel chemical compositions (Table III) have low carbon levels (approx. 0.08 wt.%) and moderate manganese levels (approx. 1.6 wt.%). The predominant alloying additions are: Ni, Cr, V, and Nb. Sulfur levels for both steels are low at 0.001 wt.%. The only significant differences between the two suppliers' materials are the 0.21 wt.% Mo addition in the GTS steel (only 0.008 wt.% in the Dillinger steel) and the 0.002 wt.% Ti addition in the Dillinger steel (none in the GTS steel).

* Tensile Strength

In the pipe made from Dillinger plate, several specimens failed to meet the nominal grade strength requirement while the remaining specimens only marginally exceeded it (Table IV).

TABLE IV: Pipe Tensile Test Results

Plate Supplier	Pipe No.	Plate No.	Specimen Location	Specimen Direction	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (% in 25 mm)	Y/T
Dillinger	1	63915	Body	Transverse	553	649	35	0.85
			Body	Longitudinal	533	643	35	0.83
		63918	Body	Transverse	542	645	34	0.84
			Body	Longitudinal	558	665	35	0.84
			Spiral Weld	Transverse	-	703[1]	24	-
			Spiral Weld	Transverse	-	672[1]	25	-
	6	98586	Body	Transverse	555	652	33	0.85
			Body	Longitudinal	576	687	33	0.84
		63919	Body	Transverse	513	635	38	0.82
			Body	Longitudinal	541	658	34	0.82
			Spiral Weld	Transverse	-	715[1]	25	-
			Cross Weld	Transverse	-	672[1]	24	-
GTS	8	3436	Body	Transverse	576	723	35	0.80
			Body	Longitudinal	603	739	30	0.82
			Spiral Weld	Transverse	-	777[1]	23	-
			Cross Weld	Transverse	-	710[1]	28	-
		3439	Body	Transverse	583	738	31	0.79
			Body	Longitudinal	591	752	29	0.79
	9	3435	Body	Transverse	593	743	31	0.80
			Body	Longitudinal	594	752	31	0.79
		3440	Body	Transverse	579	734	33	0.79
			Body	Longitudinal	588	743	30	0.79
			Spiral Weld	Transverse	-	772	25	-
			Cross Weld	Transverse	-	790	21	-
	10	3432	Body	Transverse	601	731	31	0.82
			Body	Longitudinal	551	716	30	0.77
			Spiral Weld	Transverse	-	769	20	-
			Cross Weld	Transverse	-	743	23	-
		3438	Body	Transverse	559	737	31	0.76
			Body	Longitudinal	587	754	31	0.78

1. Transverse weld tensile tests failed between 0.3 to 1in. away from weld.

On the other hand, the pipe made from GTS plate comfortably exceeded the nominal grade. Elongations were similar for both steel sources, ranging from 21 to 38 %. The GTS material exhibited significantly lower Y/T values (0.76 to 0.82) than the Dillinger steel (0.82 to 0.86).

Unlike the pipe body tests, the all-weld-metal tensile tests revealed minimal difference in properties between the two suppliers (Table V).

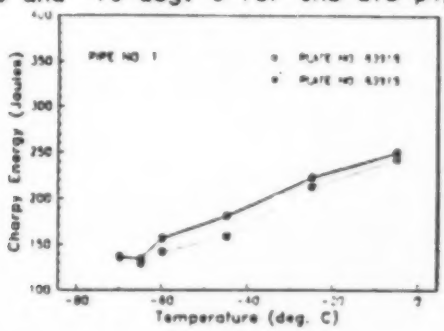
TABLE V: All-Weld-Metal Tensile Test Results

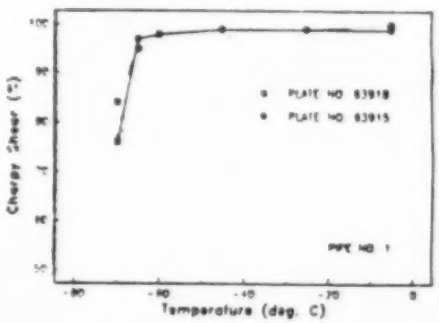
Plate Supplier	Pipe No.	Weld	Yield Strength (MPA)	Tensile Strength (MPa)	Elongation (% in 25 mm)	Y/T	Reduction of Area (%)	Yield Point Elongation (%)
Dillinger	2	Spiral	648 ± 1	683	22.8 ± 1.6	0.95	67.4 ± 3.9	3.2 ± 0.3
		Cross	604 ± 6	653 ± 1	23.3 ± 1.8	0.92 ± 0.01	66.6 ± 1.7	2.7 ± 0.2
GTS	11	Spiral	634 ± 16	677 ± 8	23.5 ± 2.2	0.94 ± 0.01	70.7 ± 2.8	2.1 ± 0.5
		Cross	591 ± 14	647 ± 4	22.5 ± 1.0	0.91 ± 0.02	67.0 ± 0.6	2.5 ± 0.3

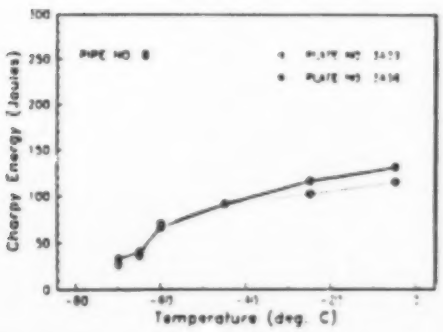
Yield strengths were well in excess of the nominal grade; for the GTS steel they were similar to the pipe body values (Table IV). Elongations and Y/T values were similar for both steel sources; however, weld metal specimens taken from pipe from both suppliers exhibited considerable yield point elongation (2.1 to 3.2 %).

*** Charpy Impact Toughness**

At -5 deg. C (a typical design temperature), the Dillinger pipe exhibited Charpy toughnesses of about 250 J while the GTS pipe displayed toughnesses of around 130 J (Figure 1 and Appendix 2). At -70 deg. C, the Dillinger pipe had toughnesses of about 140 J; whereas, the GTS pipe had toughnesses of around 30 J. Fracture appearance transition temperatures (FATT) were well below -70 deg. C for the Dillinger pipe and between -60 and -70 deg. C for the GTS pipe (Figure 2).







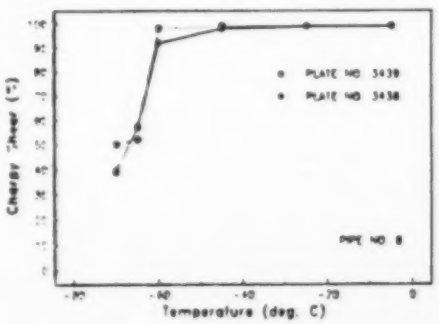


Figure 1: Charpy Impact Transition Curves for Pipe Nos. 1 (Dillinger) and No. 8 (GTS).

Figure 2: Charpy Shear Transition Curves for Pipe Nos. 1 (Dillinger) and No. 8 (GTS).

* Drop Weight Tear Ductility

Estimated Nil Ductility Temperatures (NDT) from Battelle drop weight tear tests are well below -60 deg. C for the Dillinger pipe (no. 1) and approximately -70 deg. C for the GTS pipe (no. 8) [Figure 3 and Appendix 2].

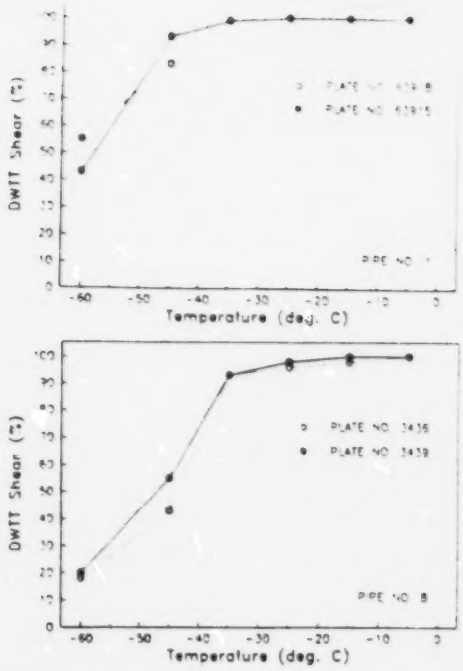


Figure 3: DWTT Shear Curves for Pipe Nos. 1 (Dillinger) and No. 8 (GTS).

* Hardness

The limits of the hardness variations for both Dillinger and GTS pipes (2 and 22, respectively) were the same; there was no significant difference between the spiral welds and cross welds (Figures 4 and 5). Hardness ranged between 200 and 300 HV0.5 with the ID generally displaying the highest hardnesses and the mid-plane exhibiting the lowest.

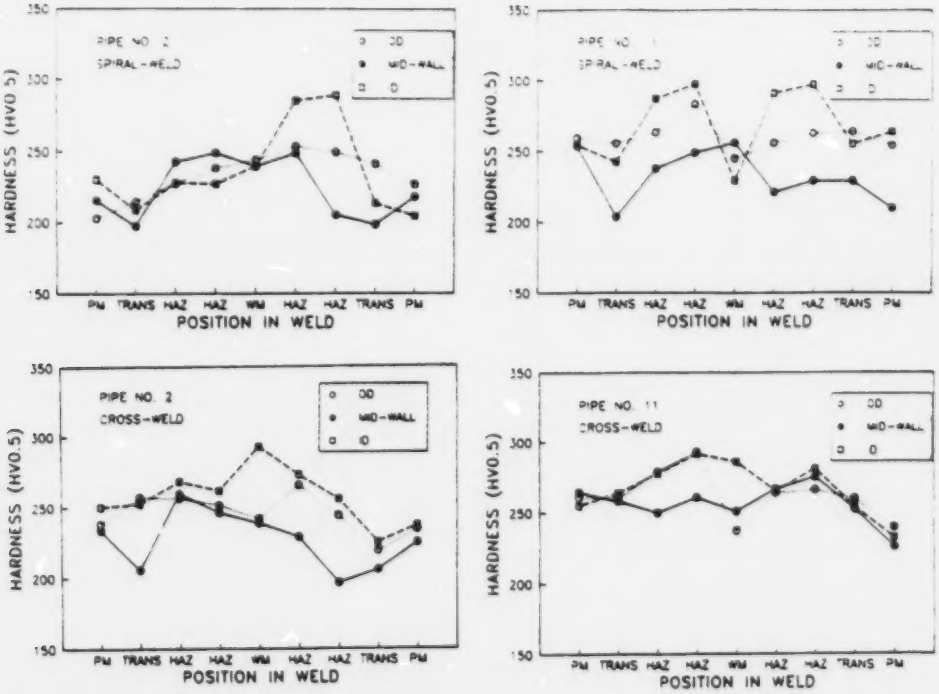


Figure 4: Hardness Traverses in Pipe Welds From Dillinger Plate (PM - parent metal; TRANS - transition zone; HAZ - heat affected zone; WM - weld metal).

Figure 5: Hardness Traverses in Pipe Welds From GTS Plate (PM - parent metal; TRANS - transition zone; HAZ - heat affected zone; WM - weld metal).

Results -Cont'd.

* HAZ Microstructure

Although the bay regions of the cross weld HAZ are wider than those of the spiral weld (figures 1A3 to 4A3), reflecting slower cooling rates due to the differences in joint edge preparation and welding procedures, the grains are equally coarse for both welds and both steels. However, there is a difference in HAZ grain size at the weld toe position adjacent to the fusion line between the two steels. Pipe no.2 exhibits coarse, elongated grains whereas pipe no. 11 contains coarse, blocky grains. Also, there is a difference in the bay region coarse grain structure between the two steels; Pipe no. 2 welds have grain boundary ferrite while pipe no. 11 welds do not.

* Guided Bend and Side Bend Ductility

All of the weld test specimens passed the guided bend and side bend tests.

* Weld Chemical Composition

There was minimal difference in weld chemical composition between the Dillinger pipe and the GTS pipe; similarly, there was no significant difference between the spiral welds and the cross welds (Table VI). There were, however, significant increases in S, Cu, Ni, Mo, Ti, and B levels over the heat chemical compositions (Table III).

TABLE VI: Weld Metal Chemical Composition

			Chemical Composition (wt%)															
Plate Supplier	Pipe No.	Weld Location	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	Ti	Al	B	O (ppm)	N (ppm)
Dillinger	1	Spiral	0.08	1.59	0.014	0.008	0.33	0.074	0.102	0.033	0.183	0.05	0.023	0.007	0.021	0.0004	334	98
		Cross	0.07	1.48	0.013	0.009	0.34	0.106	0.051	0.036	0.076	0.05	0.023	0.004	0.021	0.0004	260	114
	8	Spiral	0.07	1.63	0.014	0.008	0.32	0.088	0.112	0.033	0.203	0.05	0.022	0.009	0.021	0.0003	-	-
		Cross	0.07	1.68	0.014	0.007	0.32	0.075	0.109	0.034	0.196	0.05	0.025	0.007	0.023	0.0004	-	-
GTS	9	Spiral	0.07	1.62	0.010	0.009	0.30	0.077	0.103	0.031	0.315	0.04	0.027	0.007	0.017	0.0006	327	44
		Cross	0.07	1.66	0.010	0.008	0.31	0.076	0.109	0.031	0.334	0.05	0.029	0.007	0.018	0.0006	255	65
	9	Spiral	0.07	1.60	0.017	0.008	0.33	0.078	0.101	0.031	0.312	0.04	0.026	0.006	0.018	0.0005	-	-
		Cross	0.07	1.66	0.010	0.007	0.32	0.072	0.109	0.031	0.335	0.05	0.028	0.007	0.017	0.0004	-	-
	10	Spiral	0.07	1.62	0.016	0.007	0.30	0.085	0.106	0.030	0.317	0.04	0.026	0.007	0.017	0.0004	-	-
		Cross	0.07	1.69	0.013	0.007	0.31	0.074	0.108	0.034	0.195	0.05	0.026	0.007	0.023	0.0004	-	-

* Weld Toughness

The 50 percent shear FATT was less than -25 deg. C and the minimum impact energy, averaged from 3 tests was 48J. for both spiral and cross welds in both steels (Table VII). The spiral weld toughness was higher at all test temperatures compared to the cross welds in both steels. The GTS steel absorbed higher impact energies at a given temperature compared to the Dillinger material.

Table VII Spiral & Cross Weld Metal Charpy Toughness in Both X80 Steels

Plate Source	Weld Type	Test Temp (0° C)	ENERGY J				% SHEAR			
			1	2	3	Avg	1	2	3	Avg
Dillinger	Spiral	-6	118	128	131	128	98	98	98	97
		-15	84	98	98	94	72	88	79	80
		-25	92	92	122	102	85	87	79	87
		-35	58	79	78	61	62	68	72	64
		-45	34	55	58	42	49	42	52	48
		-60	41	22	32	28	25	25	6	21
	Cross	-6	89	92	92	94	97	95	95	96
		-15	78	58	58	72	94	72	97	87
		-25	27	43	65	48	52	52	58	54
		-35	41	29	30	40	49	38	42	47
		-45	28	28	23	26	29	43	25	29
		-60	14	14	15	14	23	28	25	29
GTS	Spiral	-6	138	144	148	142	98	97	98	97
		-15	115	121	129	122	77	77	79	78
		-25	89	72	62	78	68	57	50	58
		-35	75	69	88	77	60	54	63	59
		-45	46	28	98	57	54	45	54	51
		-60	58	30	20	36	42	25	27	28
	Cross	-6	100	123	110	111	97	95	95	96
		-15	102	87	71	87	77	95	93	88
		-25	96	58	60	71	62	55	60	59
		-35	88	80	28	92	55	53	49	59
		-45	37	22	25	28	58	32	47	45
		-60	27	28	18	25	32	40	25	32

* Field Weldability

The bend test deflection to failure of field welds averaged 6mm in both steels (Table VIII). Stelco's plate for X70 (Grade 483) pipe averaged 6.47mm deflection.

Table VIII: Weldability Bend Test Failure Deflections for X70 and X80 Steel

	BEND TEST DEFLECTION TO FAILURE (MM)		
VALUE	Stelco X70	GTS X80	Dillinger X80
No. of Heats	4	1	1
No. of Tests/Heat	2	2	2
Mean	6.47	6.00	6.02
Maximum	8.00	7.50	6.95
Minimum	5.00	4.50	5.10

Discussion

Overall, the Dillinger steel exhibited the best toughness properties while the GTS steel displayed the best strength properties. This can be attributed mainly to the higher Mo addition in the GTS steel and its affect on microstructure. Mo is a potent hardenability agent and as such, produces significant increases in strength. Correspondingly, it yields lower toughnesses and transition temperatures because of the more brittle microstructures that result. These microstructures are typically bainitic or martensitic, depending upon the amount of Mo added. The 0.21 wt.% Mo addition in the GTS steel resulted in a ferritic-bainitic-pearlitic microstructure; whereas, the Dillinger steel (with only 0.008 wt.% Mo) displayed a banded ferritic-pearlitic microstructure (Figures 6 and 7). The ferritic-bainitic-pearlitic microstructure is stronger but less tough because of the bainitic components.

Figure 6: Optical Micrographs of Dillinger Plate (500X)

a) North End

b) Center

c) South End

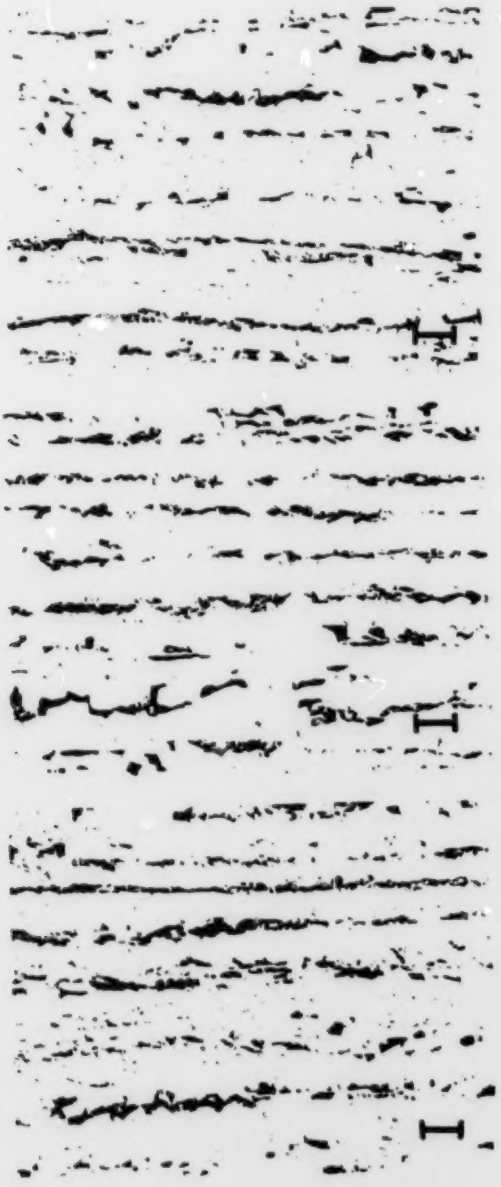


Figure 7: Optical Micrographs of GTS Plate (500x)

(a) North End

(b) Center

(c) South End

The cold forming characteristics and ductility of both the German and French steels are expected to be very good because of the low Y/T values (maximum 0.86) and high elongation values (maximum 38%).

Weld performance was comparable or better than the pipe body properties, except for elongation (Table IV). Nevertheless, the weld metal elongations were still respectable at approximately 23%. The yield point elongation in the weld metal, however, is puzzling, particularly after mechanical expansion. Furthermore, the weld metal had high Mo levels (as much as 0.34 wt.%) which usually eliminates yield point elongation. The higher Mo content of the GTS steel produced the differences in HAZ microstructure and generated higher weld metal toughness than the Dillinger material.

Many of the weld hardness values exceeded the 248 HV limit that is frequently specified for resistance to sulfide stress corrosion cracking. The higher hardnesses in the ID region of the weld are expected because of reheating (followed by rapid cooling) from the OD cap pass.

The field weldability of the X80 steels compares favourably to that of Stelco's X70 steel. Both grades exhibit bend test deflections exceeding the minimum value required to avoid HAZ cracking in field welds.

Overall, the mechanical properties of the Dillinger and GTS pipe compare favourably to published X80 properties by Sumitomo [5] and Mannesmann [6] (Table IX). From this it is apparent that Stelpipe can manufacture X80 pipe that can meet world X80 mechanical properties.

TABLE IX: Typical X80 Pipe Body Mechanical Properties Achieved by Competitive Pipe Producers

SUPPLIER	Test Direction	Y.S. (MPa)	UTS (MPa)	% El. in 50 mm	Y/T	Impact Energy at -20°C (J)
Sumitomo[5] 914 mm OD x 21 mm WT	Longitudinal Transverse	594 614	647 690	43 37	0.92 0.89	- 258
Mannesmann[6] 1422 mm OD x 16 mm WT	Not Stated	607	716	23	0.85	184

PLATE CHARACTERISTICS

Procedure

One plate (11.7 mm x 2604 mm x 17678 mm) from each supplier was held back from the pipemaking trial for mechanical testing (see Appendix 3 for a sketch of the sampling locations, test type, number of specimens, and specimen orientation).

Tensile samples were taken from five locations in the plate: north end, quarter, centre, third quarter, and south end. At both ends and the centre, two tensile samples in each of the longitudinal, transverse, and 45 degree directions were taken from the centre line and both edges (east and west) of the plate. At the two quarter positions, two longitudinal tensile specimens were taken from the centre line of the plate. The specimens were prepared and tested according to ASTM E8 [2].

Full size Charpy impact specimens were machined from samples taken from the north end and centre locations of the plates at the quarter width location. Thirteen transverse coupons were prepared from both locations in the German plate and sixteen transverse coupons were prepared from both locations in the French plate. The coupons taken from the German plate were tested at temperatures of -5, -20, -45, -70, and -100 deg. C while the coupons from the French plate were tested at temperatures of +20, -5, -20, -45, -70, and -100 deg. C. Three coupons were tested at each temperature except for -100 deg. C where only one coupon was tested. All specimens were tested according to ASTM E23 [4].

Metallographic specimens (longitudinal sections) were prepared from the north end, centre, and south end positions in the plates along the plate centre line. The specimens were examined optically for as-rolled microstructure. Mean line intercept grain size, grain aspect ratio, and area percent second phase were measured for each sample using the Steltech Image Processing System (IPS). Five fields per sample (41200 microns squared area per field) were scanned at a magnification of 500x.

Results

Both plate suppliers produced material which exhibited excellent uniformity in strength along the plate length and across the plate width (Figures 8 and 9). However, the majority of the French plate yield strength was less than 550 MPa while most of the German plate equalled it.

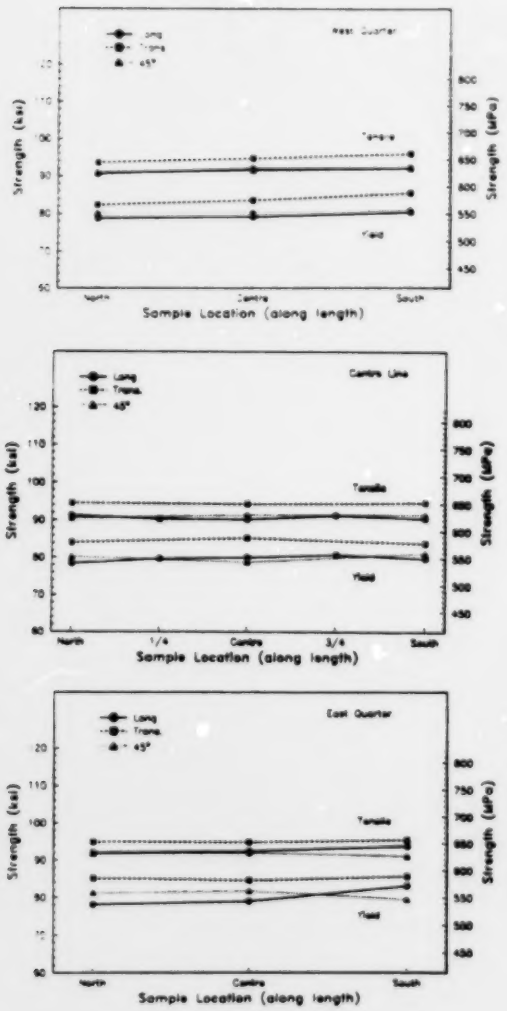


Figure 8: Variation in Strength Properties Along Length and Across Width of Dillinger Plate

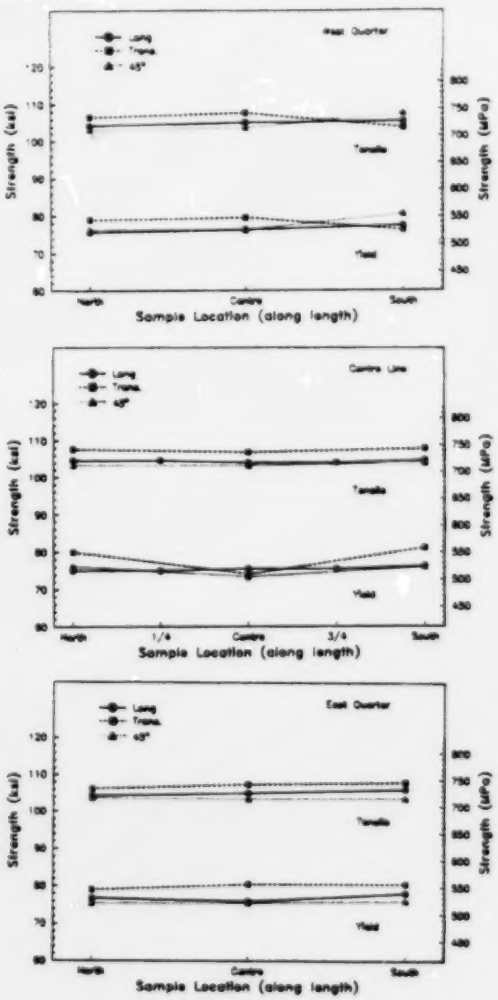


Figure 9: Variation in Strength Properties Along Length and Across Width of GTS Plate

At any given temperature, the German plate displayed Charpy impact toughnesses almost twice those of the French plate (Figure 10). Fracture appearance transition temperatures (FATT) were well below -100 deg. C for both plate sources (Figure 11). Uniformity in impact energy with location in the plate was not as good as the strength properties but was still accepta[illegible]

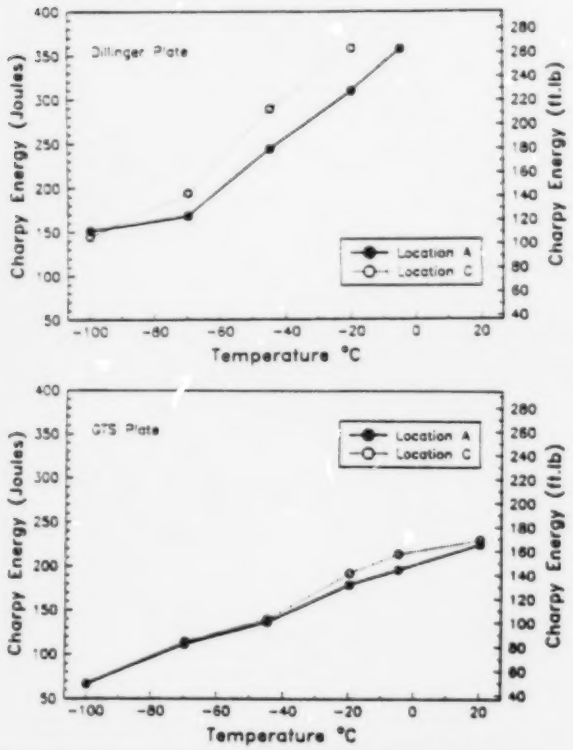


Figure 10: Plate Impact Transition Curves (Location A - North End; Location C - Center)

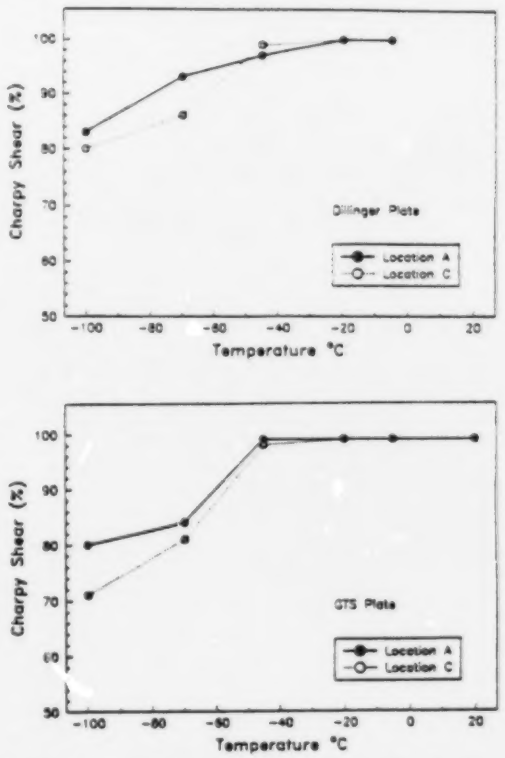


Figure 11: Plate Shear Transition Curves (Location A - North End; Location C - Center)

The German plate exhibited a banded ferrite-pearlite microstructure whereas the French plate displayed a ferrite-pearlite-bainite microstructure (Figures 6 and 7). Average grain sizes were small (5.31 to 7.15 microns) for plate from both sources (Table X).

TABLE X: Results of Quantitative Metallographic Analyses on Plate

Plate Source	Sample Location	Mean Line Intercept Grain Size (mm)		Grain Aspect Ratio		Area % Second Phase	
Dillinger	North End	7.15	7.64	1.23	1.70	13.34	2.67
	Center	6.59	6.82	1.23	1.70	13.65	1.61
	South End	6.77	6.24	1.17	1.45	11.13	0.92
GTS	North End	6.26	6.26	1.30	1.68	6.69	0.70
	Center	6.03	6.25	1.25	1.64	5.66	0.62
	South End	5.31	6.18	1.28	1.85	14.38	0.93

Also, grain aspect ratios were similar; they ranged from 1.17 to 1.30. Area percent of second phase for the German plate was approximately twice as high as that in the French plate as well as more uniform. The south end of the French plate had a much higher value than the north end and centre.

Discussion

Overall, the German plate displayed better mechanical properties than the French plate. Although the French plate did not consistently meet the nominal strength level, it gained strength during pipemaking (Table IV). The German plate, however, lost strength during pipemaking so that in several pipe the nominal grade strength requirement was not met. This can be attributed to the ferrite- pearlite microstructure which results in discontinuous yielding during tensile testing. The high Mo addition in the French plate (0.21 wt.%) promoted continuous yielding which accounts for the strength increase through work-hardening during pipemaking; the German plate had a Mo addition of only 0.008 wt.%. Greater additions of Mo and/or alterations to the plate processing (such as accelerated cooling to yield a more bainitic microstructure) would be necessary to eliminate this problem in the German plate.

Although grain sizes and aspect ratios were similar for both plate sources, there was considerable scatter in the data. This is attributed to the large distribution in grain sizes; both plates displayed mixed grain sizes.

The variation in second phase (pearlite) amount along the length of the French plate is most likely due to differences in cooling rate from end to end. Generally, a decrease in cooling rate results in an increase in the volume fraction of pearlite because of the enhanced diffusion of carbon upon transformation. However, GTS provided no information on the thermo-mechanical history of their plates; consequently, we cannot verify if there indeed was a difference in the cooling rate. Nevertheless, the difference in the amount of second phase had minimal effect on the strength and ductility properties; minimal variation in yield and tensile strength was observed (Figure 9). Moreover, no significant difference in tensile elongation was observed along the length of this plate.

REFERENCES

1. API Standard 5L, 1988, "Specification for Line Pipe".

2. ASTM Standard E8, 1985, "Tension Testing of Metallic Materials".

3. ASTM Standard A370, 1977, "Mechanical Testing of Steel Products".

4. ASTM Standard E23, 1982, "Notched Bar Impact Testing of Metallic Materials".

5. T. Hashimoto et al, The Sumitomo Search, 1988, No. 37, pp 93 to 104.

6. A. W. Gartner et al, Int. Conf. on Pipe Technology, 1987, AIM, pp 227 to 241.

ACKNOWLEDGEMENTS

The author would like to thank B. Armitage, W. Krestynski, and E. Schoen for their assistance with the plate sampling and testing.

A P P E N D I X 1

Stelpipe X80 Skelp Specification

Stelpipe

Material Specification PS-114

November 24, 1989

Grade 550 Plate Skelp

For Cold-Expanded Spiral Seam Pipe Manufacture

1. Scope

The steel plate skelp supplied to this specification is intended to be used for the manufacture of double submerged-arc spiral seam Grade 550 Cat. II gas transmission line pipe in accordance with the requirements of CSA Standard Z245.1-M86.

2. Process

The steel shall be made by the basic oxygen process and shall be fine grain, killed, and strand cast. The longitudinal axis of the finished plate shall be parallel to the longitudinal axis of the cast slab. The plate shall be furnished in the as-rolled condition.

3. Chemical Composition

The carbon equivalent shall be a maximum of 0.31% for both heat analysis and product analysis, based on the CSA formula.

No deliberate additions of tin, boron, or cerium shall be made.

For each heat, the manufacturer shall report the heat analysis and one product analysis representative of the skelp supplied. Such reports shall include all elements that are pertinent to the carbon equivalent formula and also those that are pertinent to the particular steel composition supplied.

4. Tensile Properties

Tensile properties shall be determined on coupons obtained from the quarter-width or mid-width region of the skelp at on orientation of 45° to the skelp longitudinal axis. The following properties are required:

Yield Strength (0.5% strain under load) Ultimate Tensile Strength % Elongation in 50.8 mm Yield/Tensile Ratio	Limits to be developed by agreement between the manufacturer and the purchaser.

Note: Since the effect of pipe fabrication on pipe mechanical properties varies with skelp manufacturing and pipe manufacturing variables, the requirements may need to be revised after mill trials.

5. Notch Toughness

Notch toughness properties shall be determined using drop-weight tear tests and Charpy V-notch impact tests obtained from the quarter-width position at an orientation of 45° to the skelp longitudinal axis.

The following requirements shall be met based on the use of full size test specimens; the specific test specimen size will be stated on the specific purchase order.

Table II
Minimum Notch Toughness Properties at -20°C

DWTT Shear Area		Charpy Energy Absorption	
Average of Two Specimens any Heat	All Heat Average	Average of Three Specimens any Heat	All Heat Average
60%	85%	60 J	75 J

6. Hardness

The hardness of the plate shall not exceed 300 HV30 at any location.

7. Testing Frequency

Testing frequency and location of tests shall be such as to ensure that the required chemical and mechanical properties are met throughout each heat shipped.

8. Internal Soundness

General

The plate shall be ultrasonically inspected by the manufacturer using an approved ultrasonic procedure. The acceptance criteria are:

Maximum area of individual imperfection - 4 000 mm

Total accumulated area of imperfections in any 1 m x 1 m area - 15 000 mm

Pipe Mill Inspection

The internal soundness of the plate shall be compatible with the non-destructive inspection at the pipe mill which includes:

(a) Ultrasonic examination over a 25 or 50 mm wide peripheral band at each end of every pipe prior to end bevelling. Any flaw indications with an amplitude greater than the reference standard, consisting of a 5 mm wide flat bottom notch milled to a depth of 50% of the nominal wall thickness from the back surface, shall be rejected.

(b) Visual or dye penetrant examination of the entire bevel surface at both ends of each pipe. Laminar-type discontinuities having a dimension greater than 6 mm shall be rejected.

On the basis of first non-destructive inspection of the pipe ends by the above methods, a maximum of 5% should require cut-off for laminar-type defects. Cut-off losses and/or full length pipe rejections will be accumulated with other losses for steel quality defects.

9. Surface Quality

The surface of the plate shall be visually inspected. Material with surface defects that reduce the thickness below the specified minimum shall be rejected.

In addition, surface imperfections such as cracks, slivers, scabs, blisters, pits, and excessive rolled-in scale that would result in rework at the pipe mill shall be minimized.

It is permissible to remove surface imperfections by grinding using a technique agreed to by the purchaser, provided that the minimum specified thickness is maintained. The amount of grinding required remove imperfections in any plate shall not exceed 25% of the to area.

Repair by welding shall not be permissible.

The plate shall be free from hard spots resulting from quenching or other causes.

It is desirable that the "as rolled" top surface be the top surface received at the pipe mill. It is mandatory that the "as shipped" top surface be maintained constant throughout the order.

10. Dimensional Tolerances

Thickness

To be specified on the purchase order.

Width

To be specified on the purchase order.

Length

To be specified on the purchase order.

Mass

Plate mass need not be determined, but the minimum mass shall be -3.0% for individual plates and -1.25% for lots of 20 tonnes.

Flatness

The maximum allowable deviation from a flat plate for any 3 m of plate length shall be 25 mm. The maximum allowable sheared edge deflection shall be 1.5 mm in 50 mm. The maximum allowable crossbow shall be 3 mm, the maximum allowable longitudinal deflection at the plate ends shall be 6 mm, and the plate corners shall be free from localized permanent deformation.

Camber

The maximum deviation of a side edge from a straight line shall be 12 mm over the length of the plate.

End Squareness

Ends shall be square within 8 mm over the width of the plate.

11. Marking

No die stamping is permitted. Each plate is to be legibly stencilled on the as-shipped top surface with weather-resistant paint showing the heat number, plate number, roll date, purchaser's order number, nominal thickness, width, and length. The heat number, plate number and date shall be in figures at least 150 mm high at both ends of each plate. The other required markings shall be stencilled in 50 mm high characters at a convenient location along one side of each plate.

12. Inspection

Prior to producing the steel, the manufacturer shall provide for approval by the purchaser, manufacturing procedure documents detailing the proposed chemical analysis, the proposed rolling practices, and the proposed manufacturing, inspection, and shipping procedures. During production of the order, the purchaser shall be entitled to verify that processing is in accordance with the approved procedures. The mills shall be adequately instrumented to permit such verification.

13. Mill Test Certificates

Mill test certificates showing chemical composition, tensile test results, and notch toughness test results shall be supplied for each heat of steel.

14. Defective Material

Material that does not conform to this specification will be subject to rejection and claim by the purchaser. The manufacturer may inspect material rejected by the purchaser. Disposition of rejected material shall be subject to agreement between the purchaser and the manufacturer.

A P P E N D I X 2

Additional Charpy Impact Test

&

DWTT Test Results

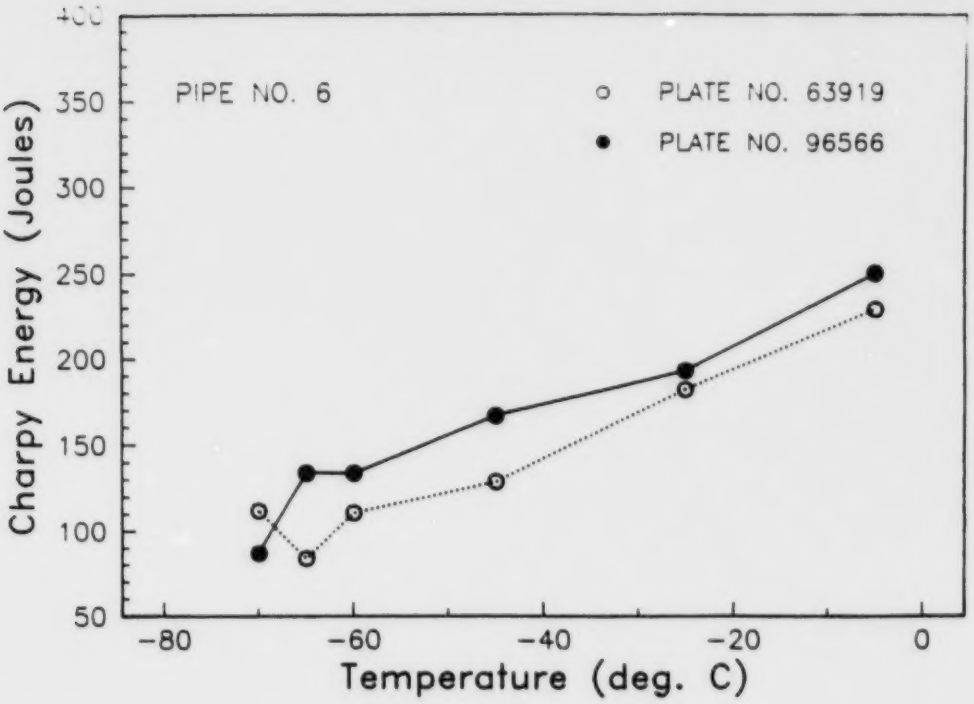


Figure 1 A2: **Charpy Impact Transition Curves for Pipe No. 6 (Dillinger)**

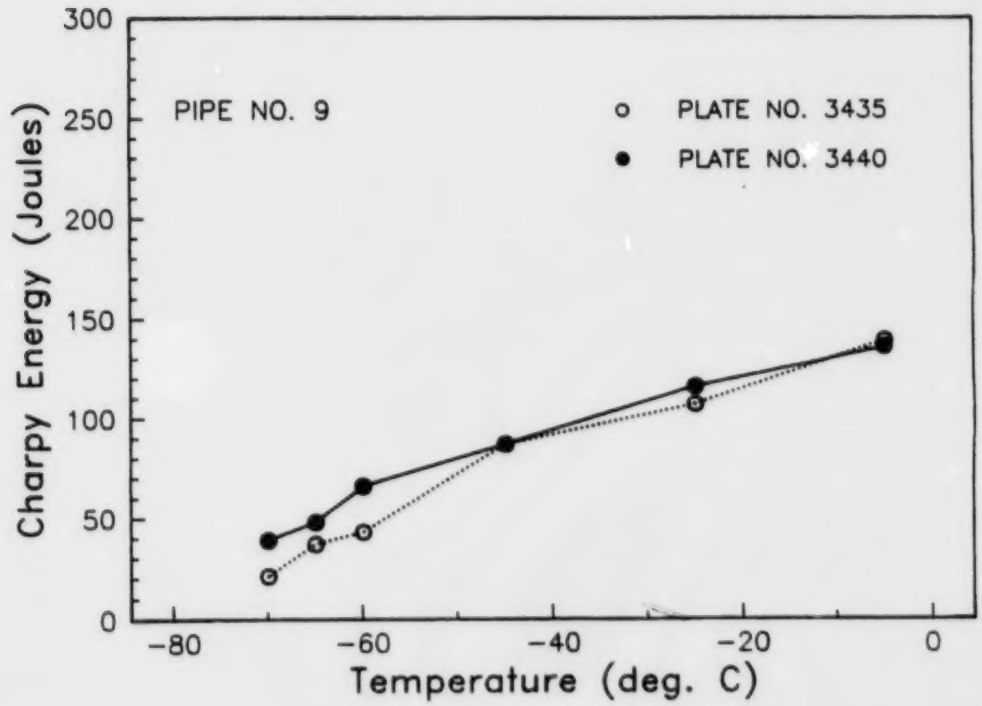


Figure 2 A2: **Charpy Impact Transition Curves for Pipe No. 9 (GTS)**

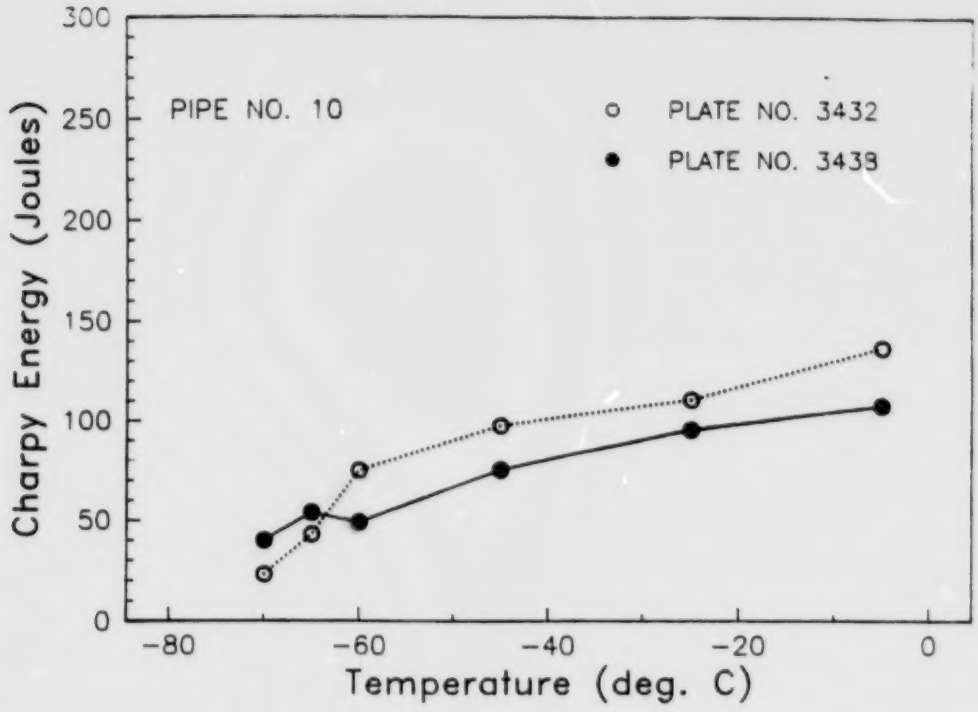


Figure 3 A2: **Charpy Impact Transition Curves for Pipe No. 10 (GTS)**

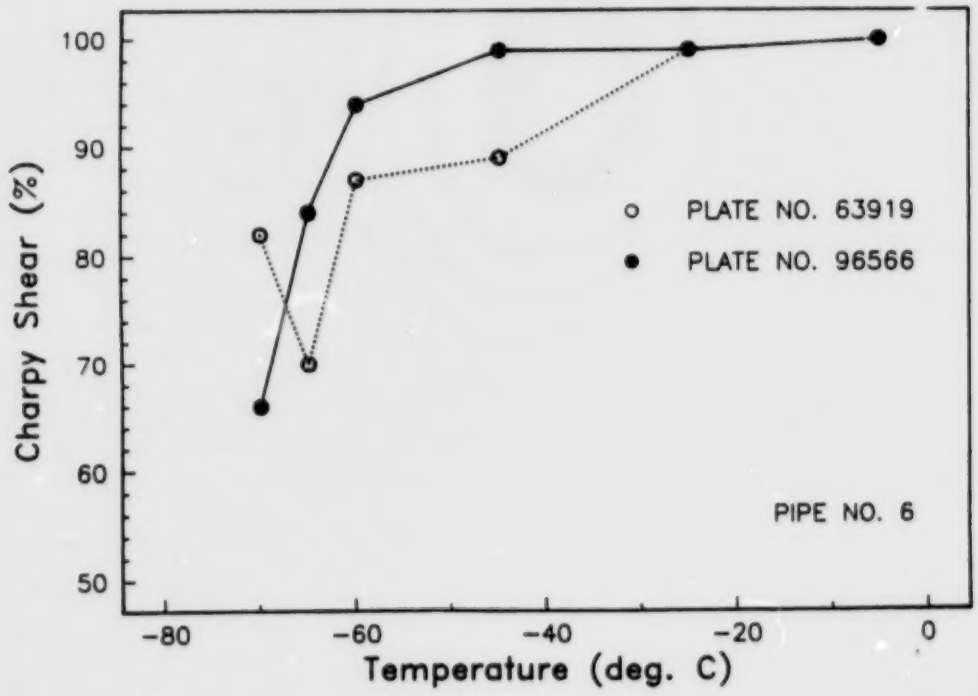
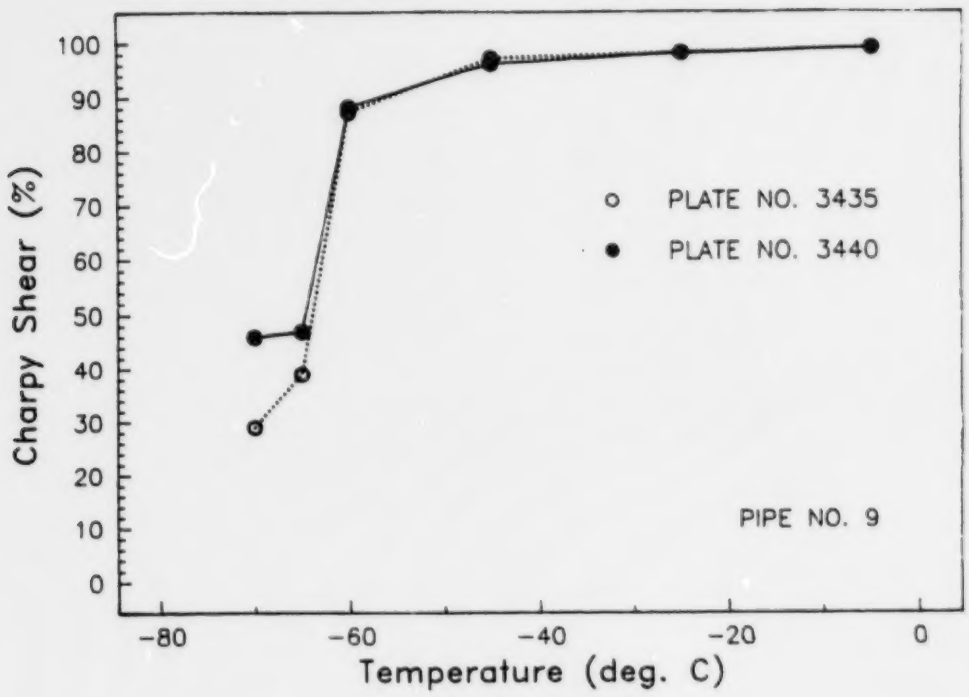


Figure 4 A2: **Charpy Shear Curves for Pipe No. 6 (Dillinger)**



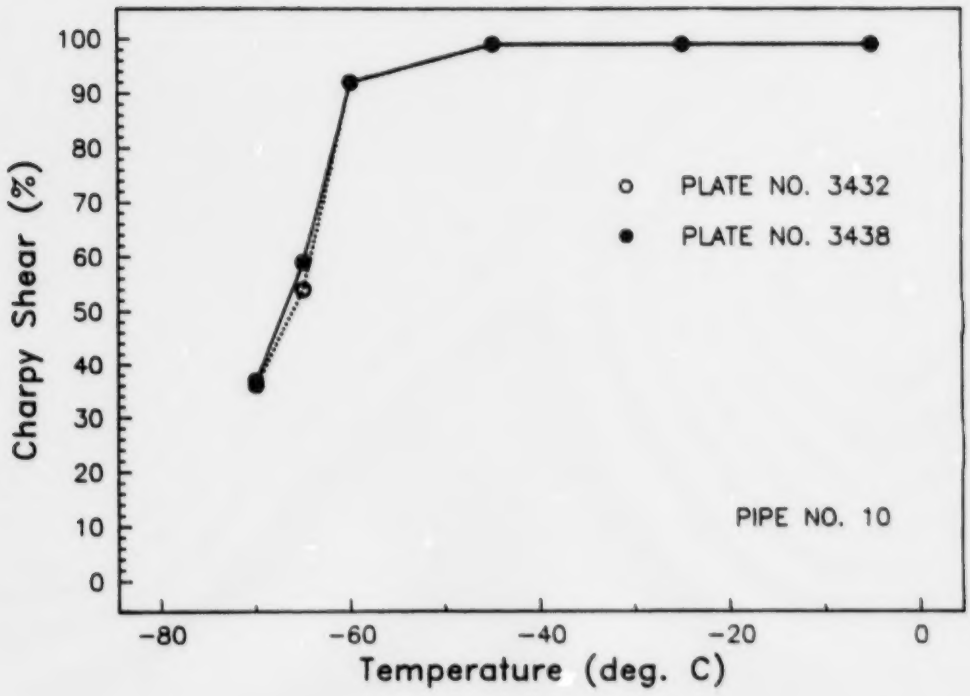


Figure 5 A2: **Charpy Shear Curves for Pipe Nos. 9 and 10 (GTS).**

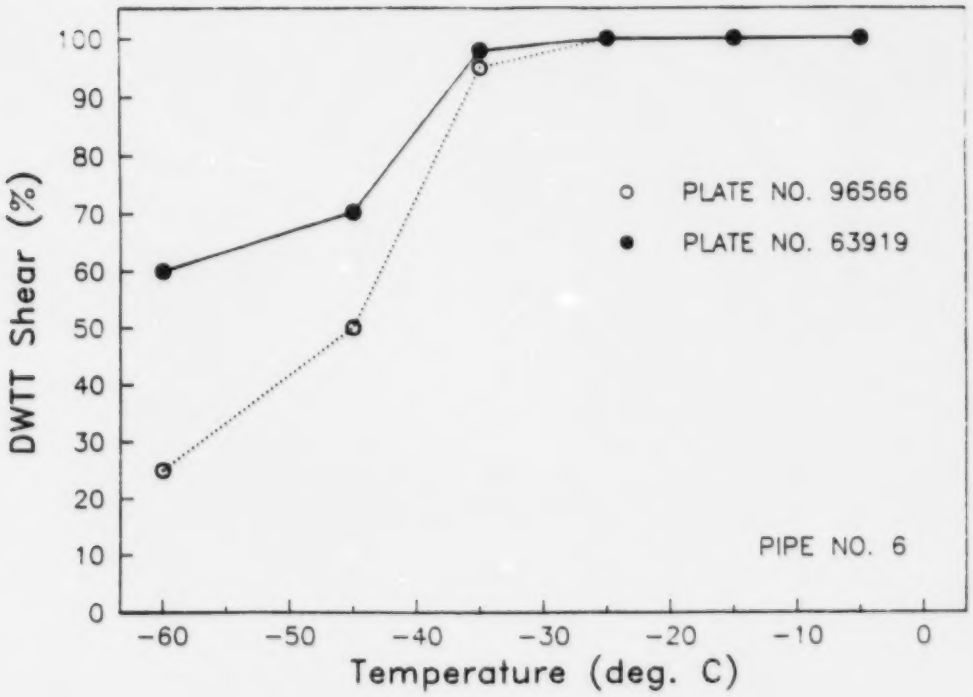


Figure 6 A2: **DWTT Shear Curves for Pipe No. 6 (Dillinger)**

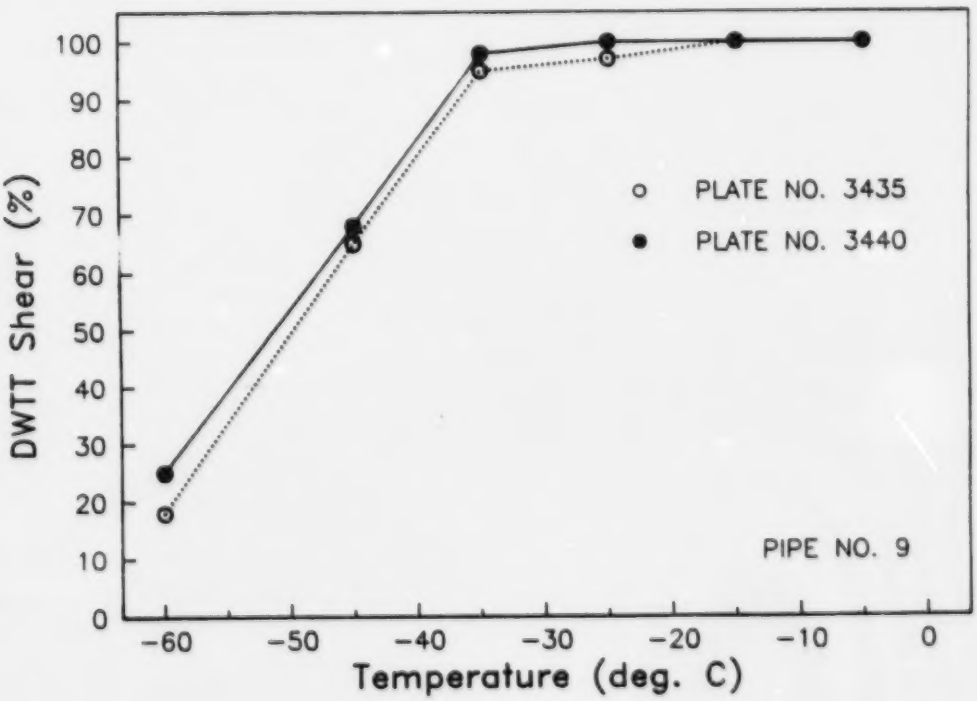


Figure 7 A2: **DWTT Shear Curves for Pipe No. 9 (GTS)**

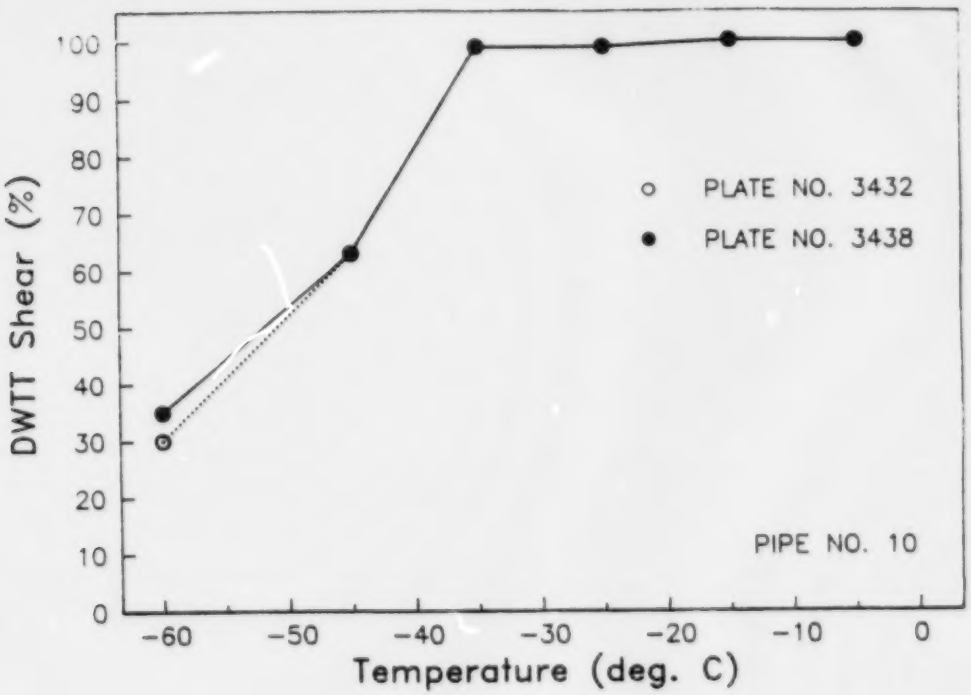


Figure 8 A2: **DWTT Shear Curves for Pipe No. 10 (GTS)**

APPENDIX 3

Plate Handling Locations

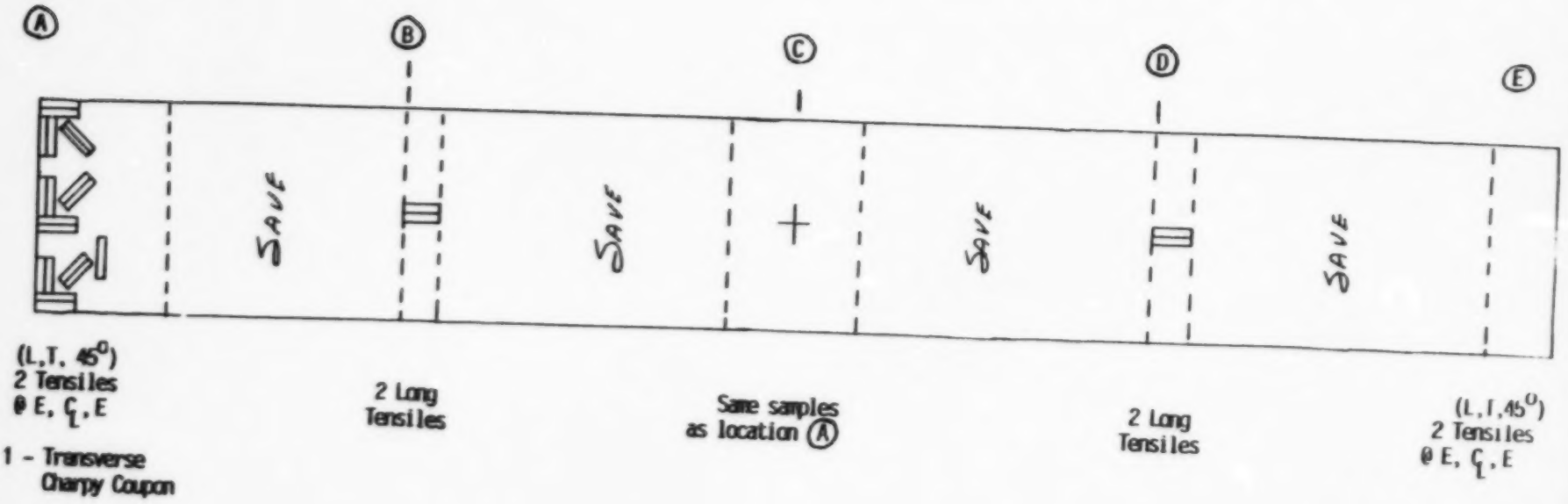
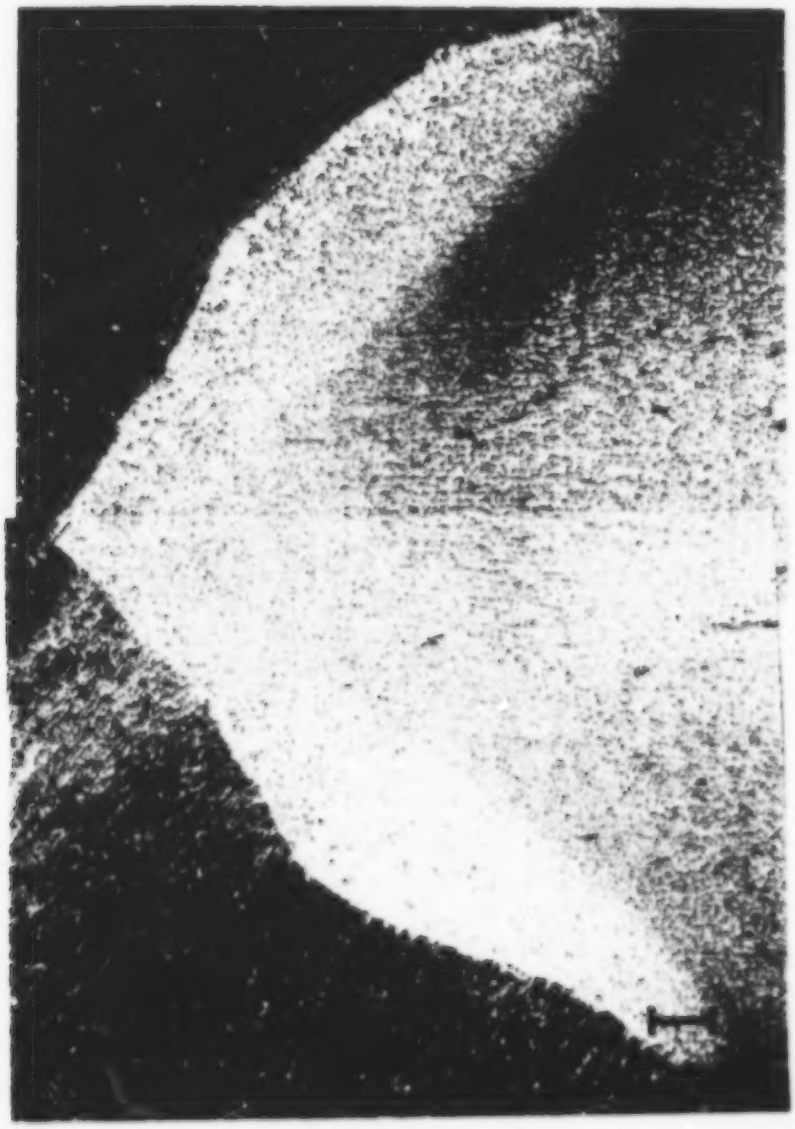


Figure 1 A3: Sketch of Plate Sampling Locations

APPENDIX 4

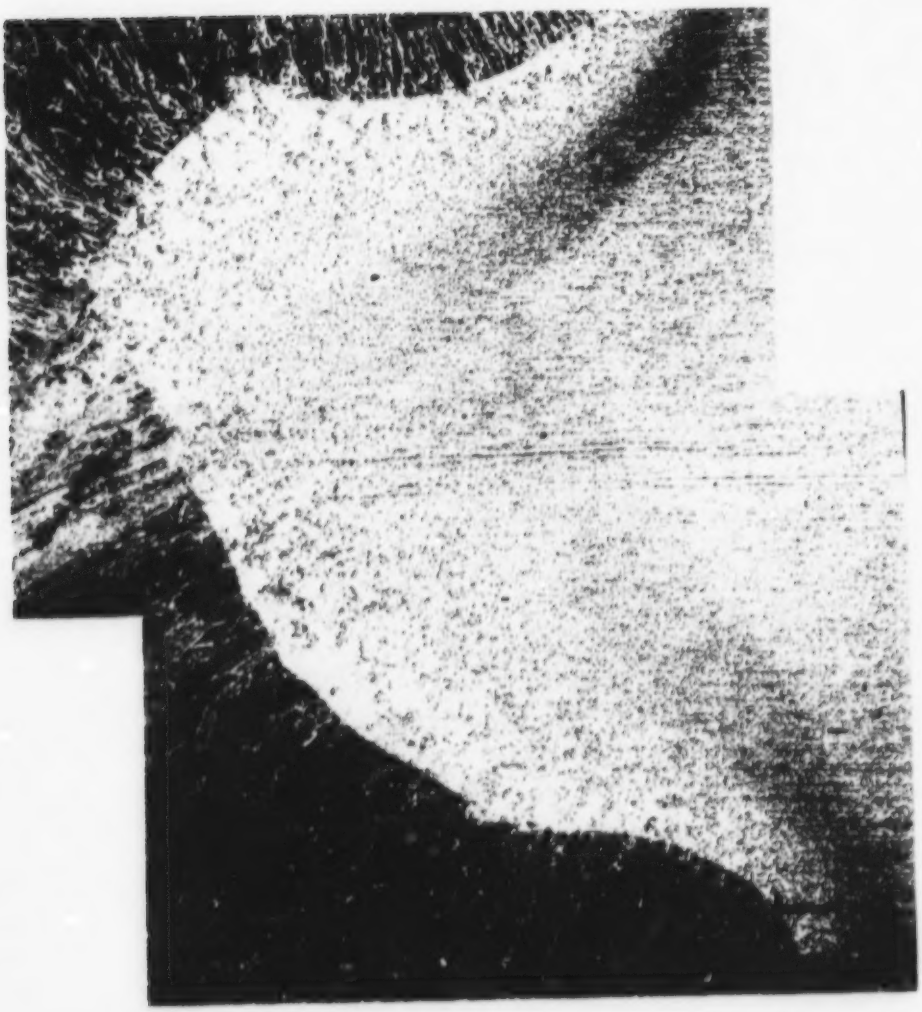
Weld HAZ Microstructure

Figure 1 A4 Spiral Weld Fusion Zone/HAZ Region of Pipe No. 2



12.5 x

Figure 2 A4 Cross Weld Fusion Zone/HAZ Region of Pipe No. 2



12.5 x

Figure 3 A4 Spiral Weld Fusion Zone/HAZ Region of Pipe No. 11

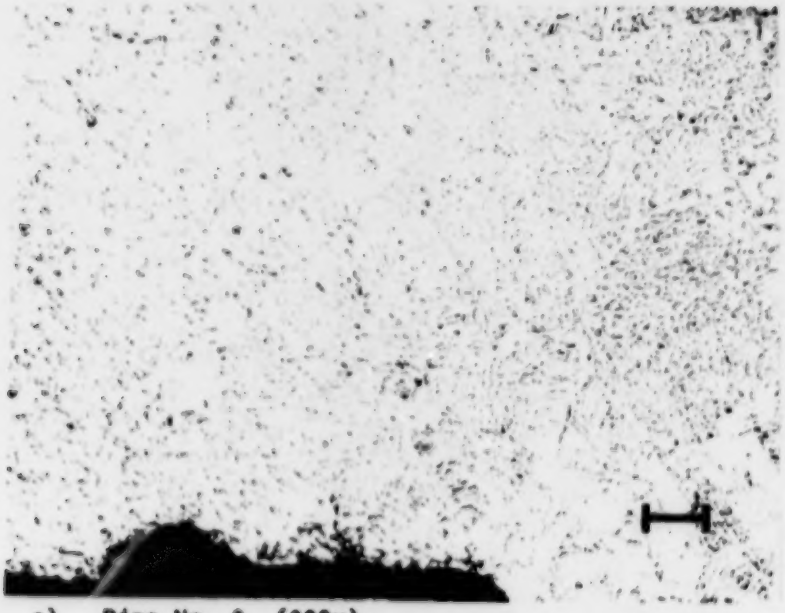
12.5 x

Figure 4 A4 Cross Weld Fusion Zone/HAZ Region of Pipe No. 11

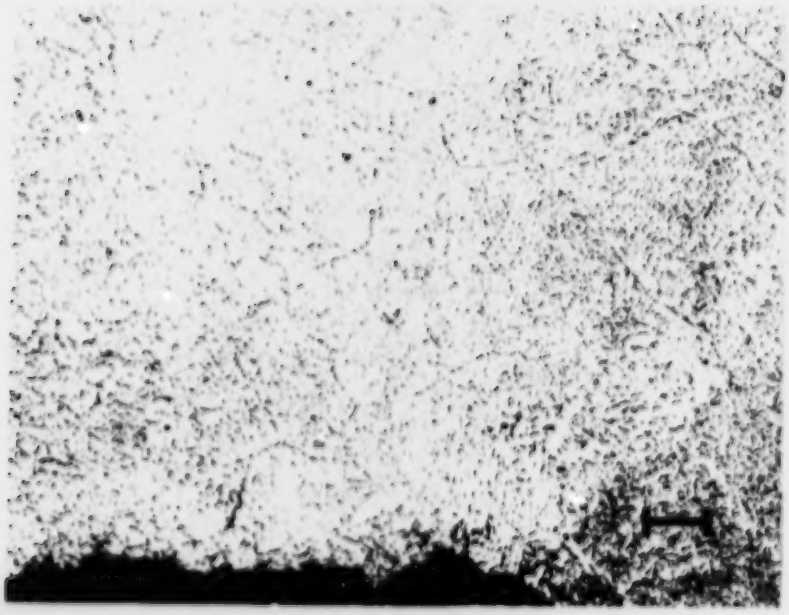
12.5 x

FRENCH PIPE (PIPE #11) CROSS WELD

Figure 5 A4 ID Weld Toe Region of Cross Welds

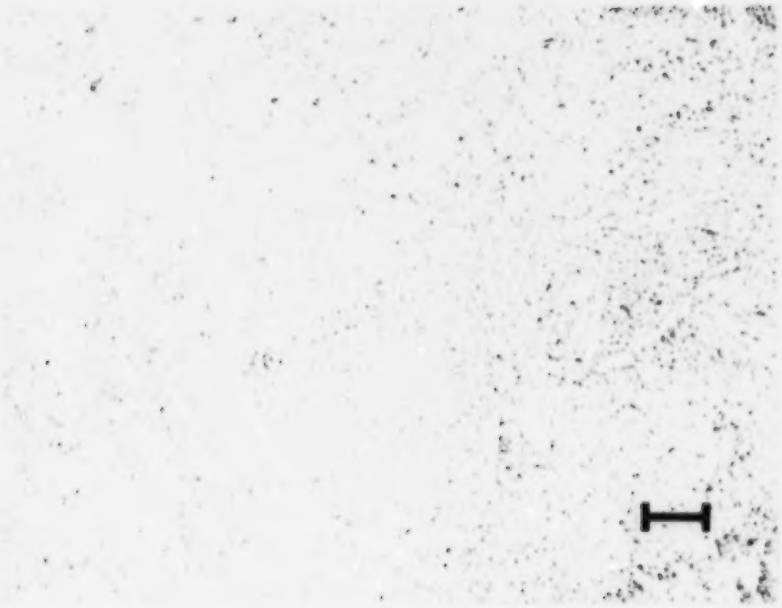


a) Pipe No. 2 (200x)



b) Pipe No. 11 (200x)

Figure 6 A4 ID Bay Region of Cross Weld HAZ



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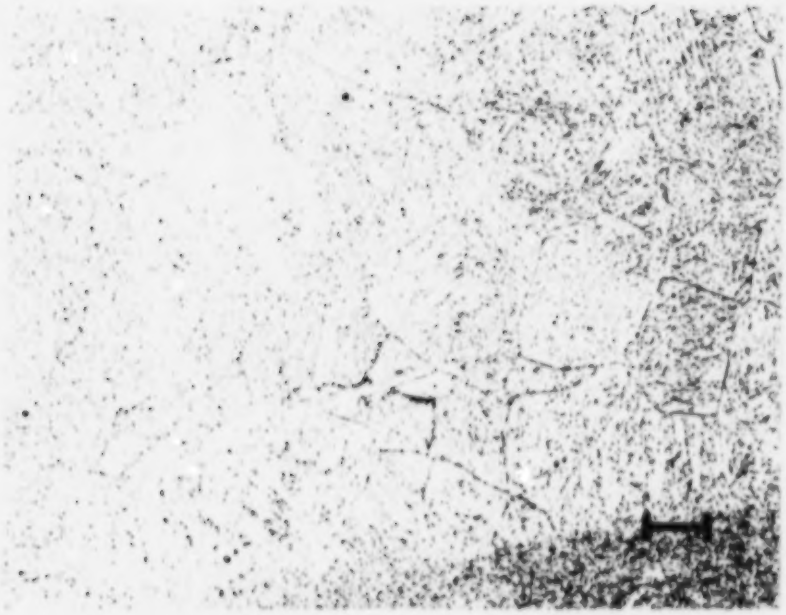
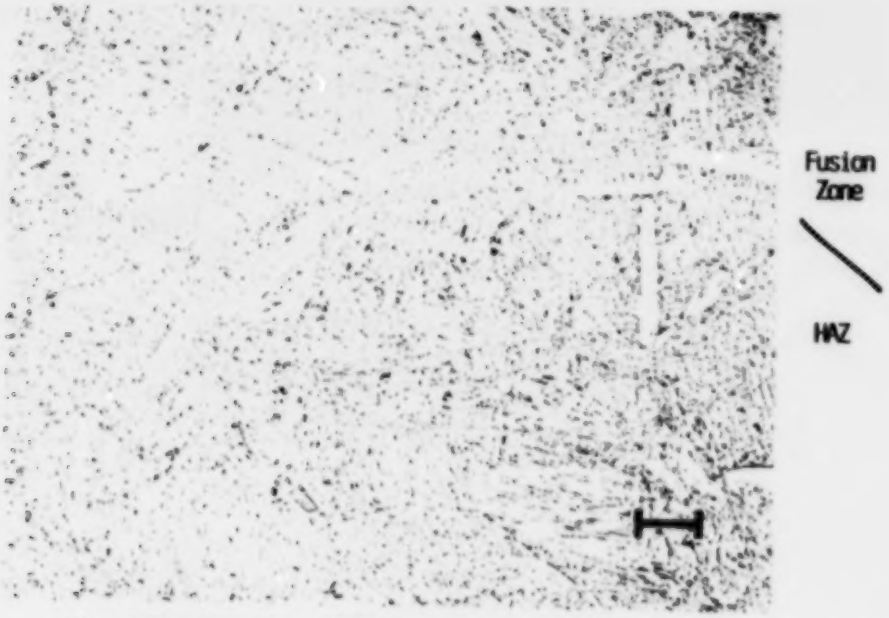


b) Pipe No. 11 (200x)

Figure 7 A4 OD Bay Region of Cross Weld HAZ



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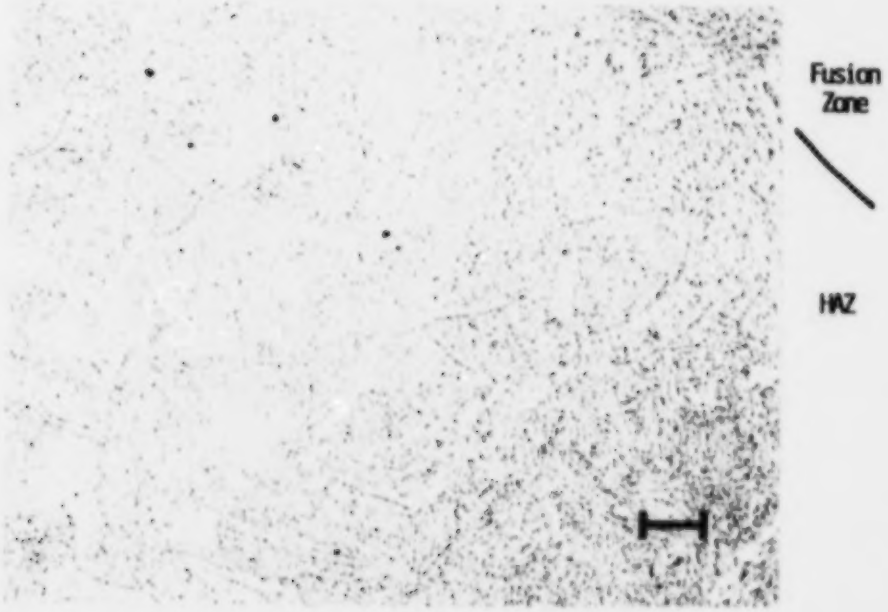
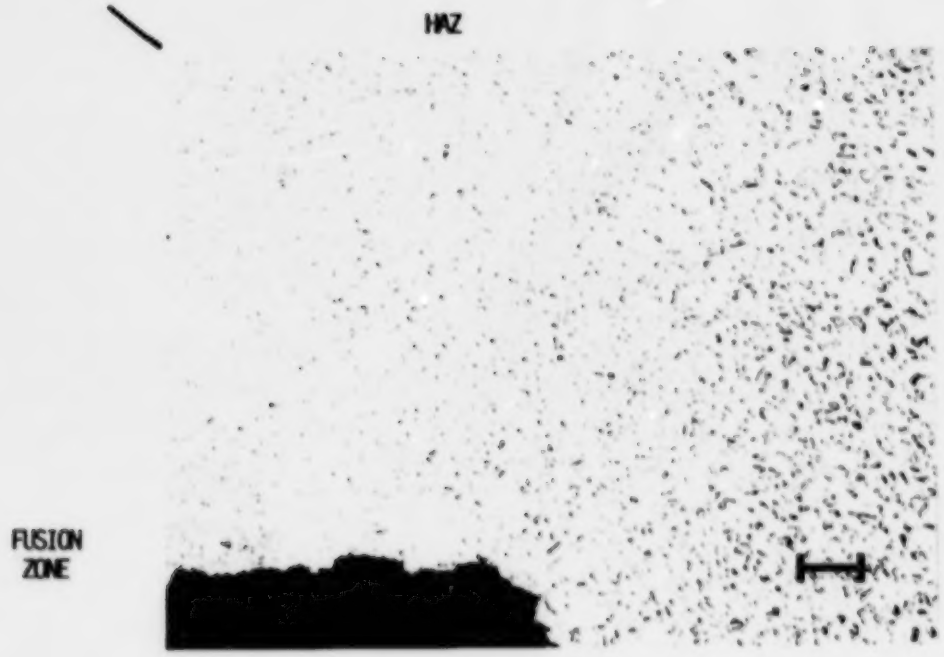
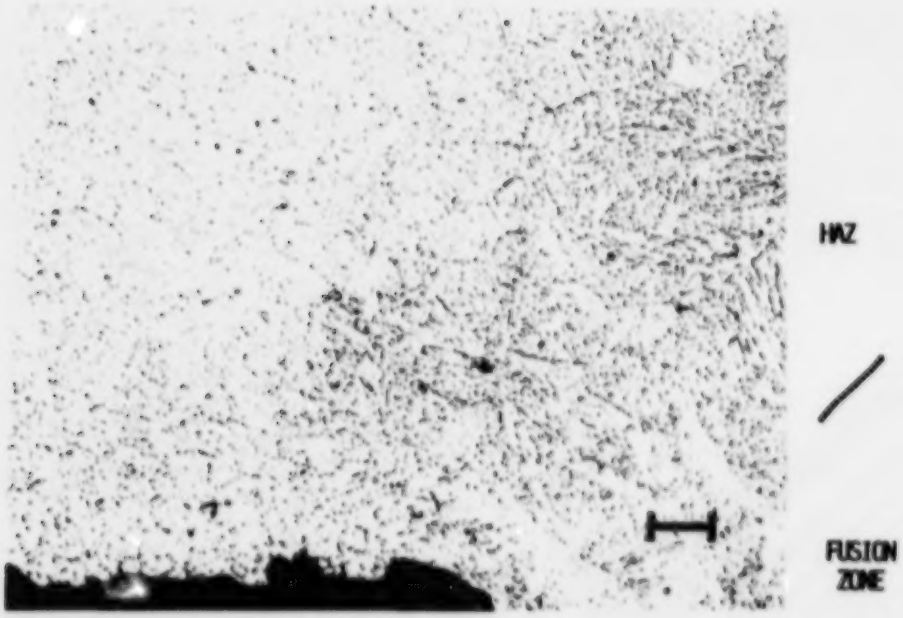


b) Pipe No. 11 (200x)

Figure 8 A4 ID Toe Region of Spiral Weld HAZ

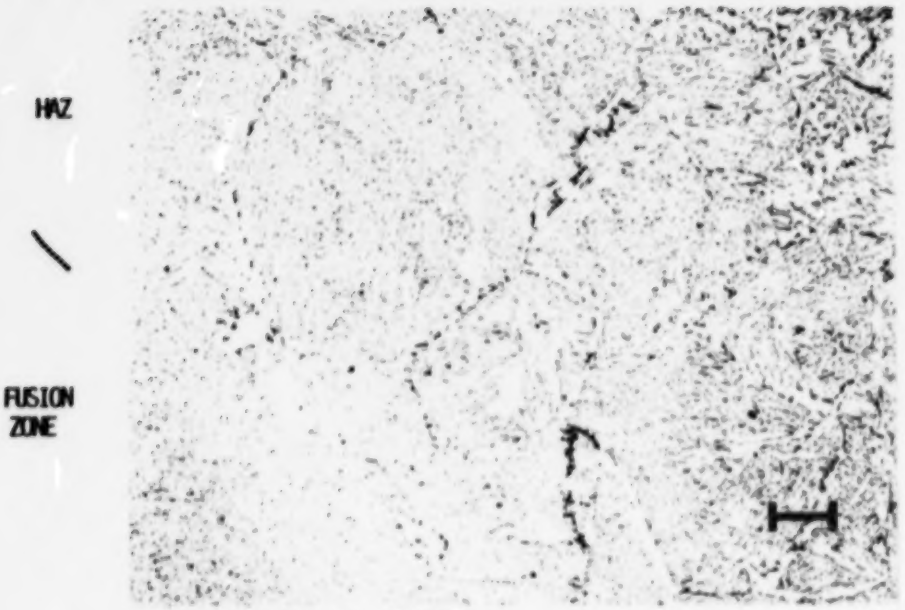


a) Pipe No. 2 (200x)



b) Pipe No. 11 (200x)

Figure 9 A4 ID Bay Region of Spiral Weld HAZ



a) Pipe No. 2 (200x)

b) Pipe No. 11 (200x)

Figure 10 A4 OD Bay Region of Spiral Weld HAZ

a) Pipe No. 2 (200x)

b) Pipe No. 11 (200x)